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Second Edition
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In Pursuit of Acoustical Equity

Controlling the temporal, spatial & spectral properties of sound





Given the intense focus on health and safety as well as the changes in work/life balance precipitated by the COVID-19 outbreak, it wasn't surprising the pandemic accelerated the healthy building movement and 'people-first' mindset extolled by standards such as WELL.

As organizations started to bring—or attempted to draw—work-from-home (WFH) staff back into the office, there was strong agreement that workplaces needed to be (re)designed with deep commitment to occupant health, well-being and social connection. There was also growing conviction amongst the A&D community that such goals needed to be achieved with attention to equity—and applied to 'real-world' needs—rather than amenities such as pool tables, private chefs and other perks; in other words, by focusing on how employees are treated rather than what they're treated to.¹

The experiences of those the pandemic pushed into WFH arrangements (via stay-at-home orders, rather than making the choice in response to their own needs) proved anything but equitable. While some employees enjoyed well-equipped workspaces within their homes, others struggled with less-than-ideal conditions (e.g. poor internet connectivity, shared workspace with children and other family members, noisy neighbors and neighborhoods) that negatively impacted their productivity and engagement. When responding to questionnaires such as Gensler's *Work from Home Survey*, many cited the need for a quiet, distraction-free environment as one of the primary reasons they wanted to return to the office.

Whether an organization wants their office to be occupied fulltime or to serve as a critical part of a hybrid working model, it has the potential to act as a "great equalizer"—a shared facility specifically designed to support all its occupants.² Supportive acoustics are vital to ensuring employees not only enjoy equal access to the facility itself, but to a key Indoor Environmental Quality (IEQ) parameter needed to work comfortably and effectively. But what is 'acoustical equity'? And how does one achieve it?

The sound that actually exists

En route to answering these questions, one must first consider the traditional approach to acoustics, which relies on ‘categorization’ and ‘acceptable-level’ schemes prevalent throughout building standards and codes. The former specifies sound-rating values (e.g. sound transmission class [STC], noise isolation class [NIC], impact isolation class [IIC], ceiling attenuation class [CAC]) for the boundaries of a room or building envelope, while the latter uses noise-rating values (e.g. noise criteria [NC], noise rating [NR], room criteria [RC]) to set maximum limits for noise, such as those generated by building systems, services, and utilities. However, neither offer insight into the ‘actual acoustics’ (the sound actually present) within a space or occupants’ experience of it.

To improve results—a goal one can, with a broad brushstroke, call ‘better acoustics’—and fulfill the objective of designing with occupants in mind, one must turn their attention to the sound actually present in a space and look at it through the lens of both architectural acoustics (the study of sound and its behaviour in and due to a space) and psychoacoustics (the study of the psychological and physiological effects of sound and its perception). Indeed, one cannot be separated from the other, as psychoacoustical evaluation of a space considers the outcome of the combined performance of all acoustical features.

Acoustical privacy is key

The reactions of building occupants are captured using psychoacoustic metrics, some of which are subjective (e.g. surveys evaluating comfort, distraction, perceived productivity) and others that are objective (e.g. intelligibility, audibility).

Research shows an occupant’s overall acoustical satisfaction is strongly correlated with acoustical privacy, a concept with clear ties to the workplace, but one that’s also relevant to other environments. Although people tend to equate acoustical privacy with speech privacy, the former isn’t limited to the intrusion of speech content; it also considers the audibility of unintelligible speech and other types of noise. For example, surveys of multi-unit residences demonstrate links between acoustical privacy and annoyance, fatigue, and sleeping problems (e.g. due to noise from traffic and neighbors).³

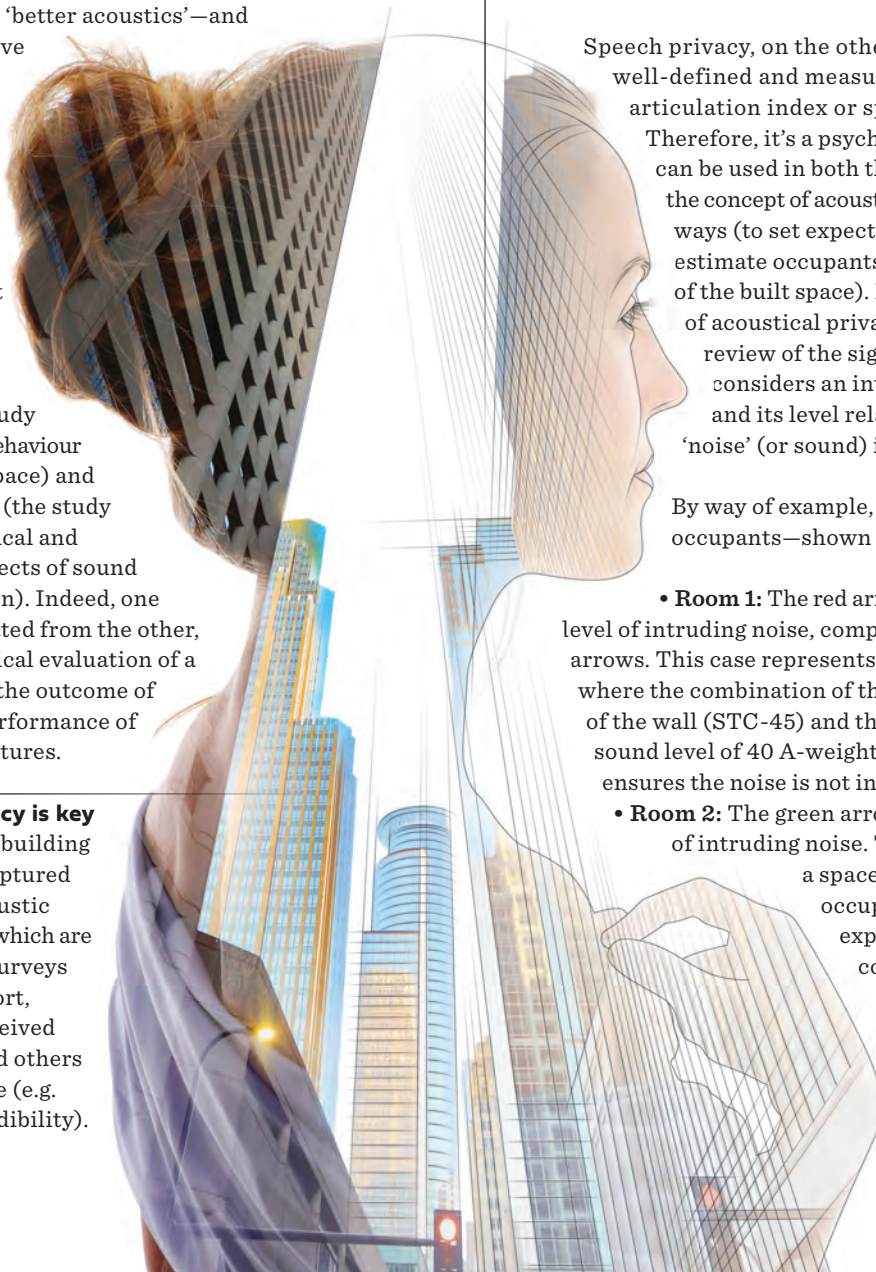
That said, it’s challenging to use acoustical privacy as a starting point for a conversation about acoustical equity. The science around acoustical privacy isn’t sufficiently nuanced; it is not yet addressed by a standardized metric or even a proposed methodology.

Speech privacy, on the other hand, is both well-defined and measurable (e.g. using articulation index or speech privacy class). Therefore, it’s a psychoacoustic metric that can be used in both theoretical (to illustrate the concept of acoustical equity) and practical ways (to set expectations during design and estimate occupants’ subjective impression of the built space). In this case, evaluation of acoustical privacy is effectively a review of the signal-to-noise ratio; it considers an intruding ‘signal’ (speech) and its level relative to the background ‘noise’ (or sound) in the receiving space.

By way of example, see the rooms—and occupants—shown in Figure 1:

- **Room 1:** The red arrows depict an elevated level of intruding noise, compared to the green arrows. This case represents a well-designed space where the combination of the insulating properties of the wall (STC-45) and the constant background sound level of 40 A-weighted decibels (dBA) ensures the noise is not intelligible and/or audible.

- **Room 2:** The green arrows depict a lower level of intruding noise. This case represents a space that fails to consider occupant needs and/or expectations. The combination of the insulating properties of the wall (still STC-45) and the existing background sound level (only 30 dBA or less) in the receiving



room is insufficient to ensure acoustical privacy. Although the intruding level of the green source is lower than the red example, it remains intelligible and/or audible.

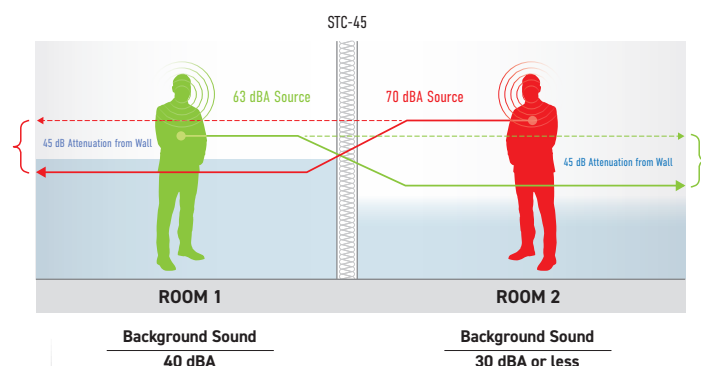


Figure 1: The person (green) in Room 1 speaks at a ‘Casual’ level, while the person (red) in Room 2 uses a ‘Normal’ level (per Pearsons). Despite the latter’s elevated vocal effort, they enjoy speech privacy due to the higher and consistent background sound level within Room 1. On the other hand, the person in Room 1 doesn’t have speech privacy due to the lower and variable nature of the background sound in Room 2; however, they believe they have privacy because they can’t hear the person in Room 2.

If one assumes the red and green signals are people speaking, the red talker’s voice carries into Room 1; however, it’s masked by the background sound. The listener in that room can’t identify and/or understand speech and the red talker enjoys speech privacy. The green talker’s voice is carried into Room 2; however, it isn’t masked by the background sound and the listener can identify and/or understand speech. The green talker doesn’t have speech privacy.

There are impacts beyond the one-way speech privacy. It’s understood the red talker has speech privacy because the background sound in the adjoining room masks the received level of their voice. However, the red talker’s ‘perception of privacy’ is violated because they can hear the green talker. This discrepancy can cause reactive behavioural changes on the part of the red talker (e.g. lowering of voice, avoiding confidential topics). It’s also accepted the green talker doesn’t have speech privacy because the background sound in the adjoining room doesn’t mask the received level of their voice. However, the green talker has a false perception of privacy engendered by the fact they’re unable to hear the red talker. This discrepancy can result in breaches of confidentiality, the implications of which can run the gamut—or gauntlet, depending on the consequences—from embarrassment to legal proceedings.

Understanding acoustical equity

One can appraise this situation using the basic dictionary definition of equity (fairness or justice in the way people are treated) and conclude the occupants don’t have acoustical equity simply by virtue of the fact they don’t enjoy equal

levels of speech privacy, or even perceived privacy. However, there’s more to the concept of equity.

According to conversations occurring in philanthropic circles, equity is also “about each of us getting what we need to survive or succeed—access to opportunity, networks, resources, and supports—based on where we are and where we want to go. Nonet Sykes, director of race equity and inclusion at the Annie E. Casey Foundation, thinks of it as each of us reaching our full potential.”⁴ Since design impacts one’s well-being and level of functioning, it’s one of the factors in life that—in the words of built environment strategist Esther Greenhouse—“has the power to disable or enable.” Greenhouse maintains if there’s a “poor fit between a person and their environment, the environment acts as a stressor, pressing down on their abilities, pushing them to an artificially low level of functioning.”⁵

The need to offer a supportive environment highlights the importance of providing beneficial acoustical conditions throughout the workplace. While occupants can be impacted by acoustical design in myriad ways, it’s important to continue with the example of speech privacy. Some might consider it a niche application only relevant to particular offices (e.g. law firms), healthcare and military environments, but surveys such as those conducted by the CBE show lack of speech privacy is the top workplace complaint, indicating it’s a broadly applicable concern.⁶ Further, this deficiency isn’t only relevant to occupants of private offices, but to those working within open plans. Although individuals within the latter group are more likely to characterize lowering speech intelligibility as reducing distractions rather than improving speech privacy, taking measures to achieve this goal means they’ll have an easier time concentrating on tasks, make fewer errors, and suffer less stress and fatigue.

The need for control

Equity involves ensuring the design provides beneficial acoustical conditions throughout the workplace to allow all occupants to function at the highest possible level, in accordance with the goals the space(s) is/are designed to meet and help fulfil. While acoustical privacy isn’t the only objective, it’s a highly sought-after quality with widespread relevance that can serve as the foundation for an acoustical plan within many types of spaces. Any deviations from (e.g. to improve intelligibility in a large training room) or additions to (e.g. biophilic sounds or music in particular spaces) the acoustical conditions required to achieve it must be intentional (designed to meet a particular goal or occupant need), not unintentional. There’s a need for control of the acoustic environment and, specifically, background sound.

Although categorization and acceptable-level schemes endeavour to minimize occupants’ negative reaction to the sound experienced within a space, they don’t control the



actual levels emitted by various noise sources (e.g. building systems), nor do they actively address the background—or ambient—sound that actually exists in the space, which experts maintain is “probably the most important room variable affecting speech privacy.”^{7, 8}

If one only implements maximum thresholds, one leaves this key variable up to ‘whatever is left’ or ‘whatever happens.’ Since the ability to discern the intrusion of speech depends on the level and spectrum of background sound “which actually exists (not the background noise criterion) in the listening space,”⁹ setting minimum—not maximum—levels for background sound is critical to attaining speech privacy. While maximum limits mitigate the impact of unwanted sound from noise sources (e.g. building systems), minimum levels call for ‘wanted sound’ from dependable sources. These two criteria are exclusive of each other, because wanted sound is needed to mask that which is unwanted.

A minimum background sound level can only be reliably achieved through the application of the ‘C’ in the ‘ABC Rule.’ While ‘A’ stands for ‘absorb’ and ‘B’ for ‘block,’ ‘C’ stands for ‘cover’—or, more accurately, ‘control’—which requires the use of a sound masking system. While ‘C’ is the final letter in the rule, it’s only because the abbreviation is meant to be memorable and is, therefore, in alphabetic sequence. It isn’t intended to assign priority level to the acoustical strategies involved or indicate the extent of the role each plays in the outcome. Rather, the rule reinforces the fact a holistic approach is required for the best results.

It’s important to note the interrelationship—and interdependency—of the acoustical features of a built environment isn’t a wholly occupant-centric consideration.

Taking a holistic approach to the execution of an acoustical plan also allows one to gain ‘system-level’ efficiencies that help manage construction-related costs (e.g. lowers STC requirements, permits walls to be built to the ceiling instead of up to the deck), allow for more effective and efficient operation of building-related systems, and avoid post-completion noise mitigation efforts.

Looking beyond level

The role ‘C’ plays in providing beneficial acoustical conditions becomes even clearer when one considers there’s more to human experience of sound within the built environment than overall level—or, more colloquially, ‘volume’—particularly at the lower decibels established by minimum and maximum limits. At these levels, the psychoacoustical impacts have less to do with the magnitude of sound (in that the mechanisms that cause temporary or permanent hearing loss due to sudden or prolonged exposure to sufficiently elevated sound levels are entirely absent) and more to do with its temporal, spectral and spatial qualities.

These qualities aren’t as well understood by those outside the acoustical community and, hence, not typically as well-considered when designing a space. If the sound that actually exists within a space is left to various noise sources (e.g. building systems), these qualities are also inherently variable—and will remain so, despite efforts to reduce, absorb and block noise—unless ‘C’ is implemented.

Temporal

The temporal component of sound refers to the variation in the level of sound as a function of time; in other words, from one moment to the next.

Neither HVAC nor mechanical, electrical and plumbing (MEP) systems can be relied upon to provide continuous and constant (unchanging) control—and nor should they, for reasons relating to the spectral characteristics of these noise sources. Figure 2 illustrates the issue. While the receiver experiences a moment of privacy (highlighted in blue), they aren't free from distraction the remainder of the time because the signal-to-noise ratio is positive. When 'C' is applied, it not only improves speech privacy, but also increases occupants' perception of acoustical consistency by reducing the frequency and severity of the intermittent changes in sound levels (dynamic range) caused by speech and noise, over time.

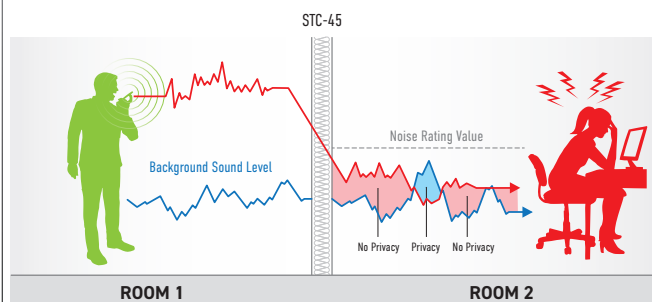


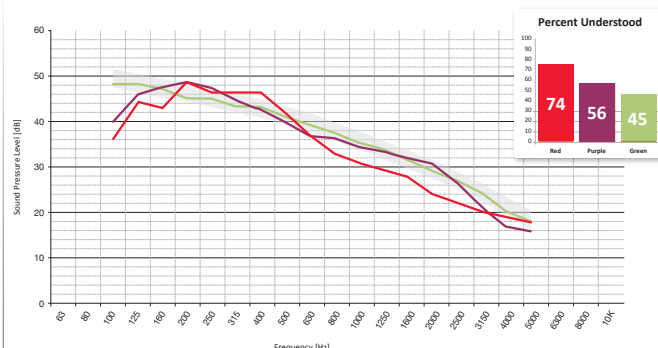
Figure 2: The person in Room 1 briefly has speech privacy—and the person in Room 2 a corresponding reprieve from disruption—when the background noise produced by the HVAC system temporarily reaches the level required for privacy, highlighting the need to establish minimum background sound levels in addition to maximum noise thresholds.

Spectral

The spectral component of sound is a more nuanced topic. Just as visible light comprises a range of wavelengths, sound, as one hears it, is the result of a combination of frequencies.

Singular—or discrete—frequency values are called 'tones,' and the human ear can hear between approximately 20 and 20,000 hertz (Hz). To simplify reporting data for the nearly 19,980 individual frequencies, it's common practice to divide this range into sections called 'fractional octave bands.' The customary fractions are full octave bands (also referred to as '1/1') and one-third octave bands (or '1/3'). Between 20 and 20,000 Hz, there are 29 one-third octave bands. The combination of all audible frequencies of a sound sum to its overall level.

It's possible for two sounds equal in overall level to be perceptibly different. Borrowing descriptors from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), one can generally state a sound that has too much low-frequency content is 'too rumbling,' while a sound that has too much high-frequency content is 'too hissy,' and sound that has too much mid-frequency content has a strong 'hum' or 'buzzing' quality.



Sounds equal in overall level can be perceptibly different, depending on their frequency content. Differing spectrums also impact speech privacy. Here, a masking system is tuned with varying degrees of precision. Despite the fact the resulting sounds are at the same overall level (47 dBA), note the impact on comprehension (i.e. privacy) when the frequencies defined by the National Research Council (NRC) masking spectrum aren't met.

If empowered with the ability to adjust the frequency content for a fixed level of sound (e.g. 45 dBA), there exists a favourable combination of frequencies that's 'most comfortable' or balanced. This 'shape of sound' is documented in literature by Beranek (and BBN) and Warnock—and, more recently and precisely, by the National Research Council of Canada (NRC)—and forms the basis for the synthesis of masking sound. When professionally tuned to meet this 'shape' (typically called a 'spectrum' or 'curve') for the majority of the audible frequency range (100 to 10,000 Hz), background sound resides in the 'Goldilocks' zone. Occupants' perception of the final product may be described as quiet—free from rumble, hiss or buzz; further, the overall level is neither too high to disturb occupant comfort, nor too low to compromise acoustical privacy.

Spatial

The spatial component of sound is no less complex. It refers to the variability of the level—also, inherently, that of the spectra—of sound, in space. These variations are a function of many parameters, including not only the source and location from where the sound originates (e.g. building systems, occupants, appliances, and even oneself), but also the space's architecture (size, shape, geometry) and fit out (finishings, fixtures, furnishings).

As sound from a source is generated, it propagates with its level decaying as a function of distance, and by the number of times it's reflected (loses energy) from other surfaces or at room boundaries. While its energy continually dissipates, its eventual inaudibility isn't because its level is attenuated below one's auditory threshold, but because it drops below the background sound in one's environment. This phenomenon is known as the Masking Effect, where the background sound covers the propagating noise. Figures 3 and 4 provide

simplified modelling of this effect. Not only does masking sound reduce the distance over which a noise can be heard (sometimes referred to as the ‘radius of distraction’), it creates a more consistent—and equitable—acoustical experience for occupants, both in their individual work areas and as they move throughout the space.

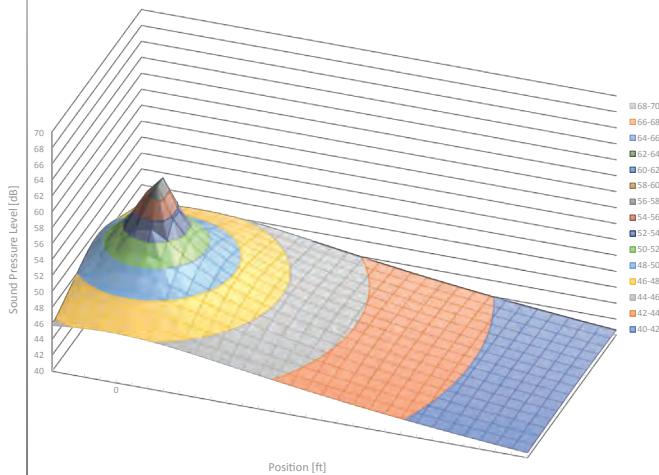


Figure 3: A simplified model showing how sound propagates as it moves away from a source, across—or, rather, throughout—a space. Each notch along the horizontal axis represents 1 ft (0.3 m), with ‘0’ marking the origin of the noise.

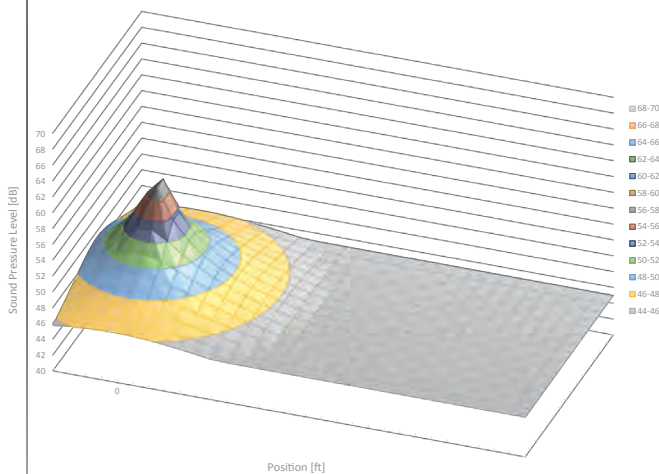


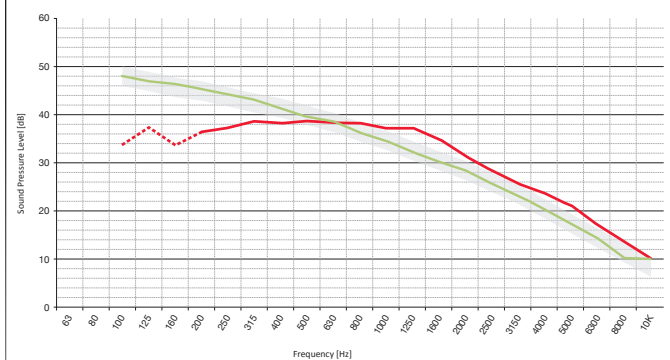
Figure 4: A simplified model showing how masking reduces the distance over which the noise shown in Figure 3 can be heard. The effect is noticeable in terms of where the propagating signal reaches and falls below the level of masking sound (grey shaded area).

Control versus cover

While many still associate the ‘C’ in the ‘ABC Rule’ with ‘cover,’ ‘control’ is a more accurate term, for several reasons.

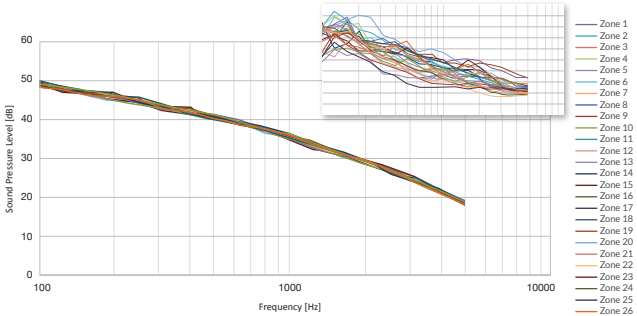
Use of the word ‘cover’ can unintentionally reinforce the view this crucial element of architectural acoustics simply involves placing any sound on top of others—like a blanket—strengthening the historical misperception that only level matters; in other words, a sound only needs to be ‘louder’ than other sounds to provide the Masking Effect and, hence, meet the requirements of ‘C.’ This misperception opens the door to commoditization of sound masking systems—the notion the effect will simply be provided by the product, rather than in tandem with a service that ensures the sound actually meets the specified masking spectrum.

The study of architectural acoustics demonstrates the physics of the behavior of sound within the built environment is exceedingly complex—and this is true for any sound, even those introduced via a sound masking system. Regardless of the sophistication of the technology, the system’s layout or loudspeaker orientation (e.g. upward-facing within the plenum or downward-facing using cut-throughs), the full Masking Effect can only be achieved through skilled field commissioning—or ‘tuning’—which adapts the sound actually produced in the room/space by accounting for its architecture, fit out and other variables. Small zones (no larger than one to three loudspeakers in size) offering fine volume (in 0.5 dBA steps) and frequency (1/3-octave) adjustment capabilities provide the technician with frequent and precise control points across the environment, helping to consistently achieve the Masking Effect throughout the space and, hence, a better outcome for occupants.



The behavior of sound within the built environment is highly complex, including that introduced via a sound masking system, regardless of its design or the orientation of its loudspeakers. If the measured output—the background sound produced in the space—is to meet the specified spectrum, the system must be professionally tuned post-installation. Here, a tuned system (green line) with upward-facing, in-plenum loudspeakers meet the NRC spectrum (grey shaded area), while an untuned system (red line) featuring downward-facing or ‘direct field’ loudspeakers fails to do so. Also note that, in the latter case, levels below 200 Hz (dashed red line) are contributed by building systems rather than the loudspeakers.

Post-installation tuning and performance verification are crucial to ensuring the sound masking system is, in fact, effectively controlling the spectrum and level of the sound that actually exists within the built environment—and, hence, dependably providing the Masking Effect throughout the space. It's only under these assured conditions—temporally, spectrally and spatially consistent acoustics—that occupants can appreciate acoustical privacy.



These background sound level measurements were taken in 26 locations within an open plan. Without masking (inset), the occupants experienced varying acoustical conditions across the space. Since masking sound was applied and tuned to reliably meet the National Research Council (NRC) masking spectrum within each small zone, occupants experience a far more consistent level of acoustical privacy and comfort throughout the space.

In conclusion

In 1962, William Cavanaugh et al., authors of *Speech Privacy in Buildings*, affirmed acoustical satisfaction couldn't be assured by any single parameter, forming the foundation for the 'ABC Rule' of architectural acoustics. However, until recently, building codes, standards, and certification programs largely focused on 'A' and 'B,' while 'C' often succumbed to a historical preoccupation with limiting the 'loudness' of sound and corresponding belief that the goal is to make spaces as silent as possible. That said, architectural acoustics are amid a paradigm shift.

In the pursuit to better understand how one can be psychologically and physiologically supported by the spaces they inhabit, the important role played by 'C' becomes apparent. Sound will always remain within the built environment, and the impact of such low-level background sound—that which actually exists in the space—cannot be separated from acoustical satisfaction and its equitable delivery. Therefore, controlling it is as important as controlling the 'signals.'

As Greenhouse states, the built environment “impacts us whether designed well or poorly, so why not design well?”

If one is to reliably design buildings to function acoustically for their users (e.g. provide adequate speech privacy, freedom from distraction, reduced annoyance, a good night's sleep, and so on), one needs to establish a known level of spectrally neutral (or balanced) background sound, rather than leaving it—and the end result—in question.

¹ Talitha Liu and Lexi Tsien in “The Office as We Knew It No Longer Exists,” *Azure*, September 2020.

² See Hao Ko and Lisa Cholmondeley’s “Equity, Interrupted: How a Return to the Office Is Needed to Rebuild Equity” at www.gensler.com/research-insight/blog/how-a-return-to-the-office-is-needed-to-rebuild-equity.

³ B. Rasmussen and O. Ekholm, “Is noise annoyance from neighbours in multi-storey housing associated with fatigue and sleeping problems?” in *Proceedings of the 23rd International Congress on Acoustics (ICA)*, Aachen, Germany, 2019.

⁴ For a brief but insightful discussion of what ‘equity’ means, see Kris Putnam-Walkerly & Elizabeth Russells “What the Heck Does ‘Equity Mean?’” at https://ssir.org/articles/entry/what_the_heck_does_equity_mean.

⁵ For more on this subject, see “Equity by Design: Redefining Senior Living,” A Conversation with Stephanie Firestone, Esther Greenhouse, and Dr. Bill Thomas’ at <https://genslerpodcast.medium.com/equity-by-design-redefining-senior-living-a-conversation-with-stephanie-firestone-esther-12a288bd852>.

⁶ See K.L. Jensen’s “Acoustical quality in office workstations, as assessed by occupant surveys,” presented at Indoor Air 2005, as well as D. Artan, E. Ergen and I. Tekce’s “Acoustical Comfort in Office Buildings,” from the proceedings of the 7th Annual International Conference - ACE 2019 Architecture and Civil Engineering.

⁷ J. Keranen and V. Hongisto, “Prediction of the spatial decay of speech in open-plan offices,” *Applied Acoustics*, vol. 74, 2013.

^{8,9} W.J. Cavanaugh, W.R. Farrell, P.W. Hirtle, and B.G. Watters, “Speech privacy in buildings,” *The Journal of the Acoustical Society of America*, vol. 34, no. 4.



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